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SOME PHENOMENA OF FLUID MOTION AND THE CURVED FLIGHT OF A BASE BALL

BY PROFESSOR W. S. FRANKLIN

IT is widely believed that a descriptive science like botany is fundamentally and essentially different from a mathematical science like physics. The one certainly does contain all that is vital in art in its sympathy with observed life and its interest in natural form as of leaf and flower; whereas the other is usually thought of as the negation of art in its interest in dead material and its dependence upon the highly conventional and abstract forms of algebra. This point of view was generally held even among scientific men half a century ago, but it is now relegated to that overflowing museum of caricatures, which it seems to be the chief function of the old-fashioned classifying philosophy to fill.

All science is descriptive. The object of this paper is to illustrate a descriptive phase of physical science, and the paper is put into the form of picture-and-legend to emphasize its descriptive character. The paper is incomplete, however, in one respect, namely, in respect to How much? How far? How long? Indeed it is in connection with this quantitative aspect of physical science that algebra is mostly used, and it is here that the essentially descriptive character of the science is nearly lost sight of. There is, however, something essentially descriptive in the use of algebra honestly according to what may be called the Maxwellian method, where algebraic forms spring full-fledged and rich from highly elaborated physical ideas, and there is little besides humbug in the method so elegantly employed by Ampère and so often employed by others where the natural path to a discovery is obliterated and replaced by elaborate algebraic synthesis *after the discovery has been made.*

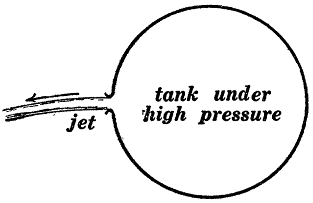


FIG. 1.

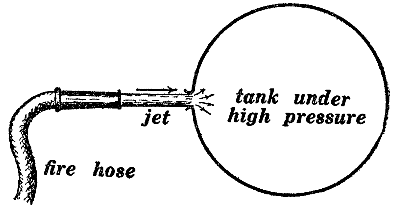


FIG. 2.

In the tank the water has a high pressure and low velocity, and in the jet the water has low pressure and high velocity. Fig. 2 represents a fancy method for pumping water into a steam boiler; namely, by squirting a jet of water at a hole in the side of the boiler.

The steady curvature of path of a rapidly spinning baseball is explained on the basis of a principle which was first enunciated by Daniel Bernoulli in 1726. Bernoulli's principle is illustrated in Figs. 1 and 2. *In a stream of water or air the pressure is high where the velocity is low, and the pressure is low where the velocity is high.* There are certain limitations to this principle which need not be discussed here.

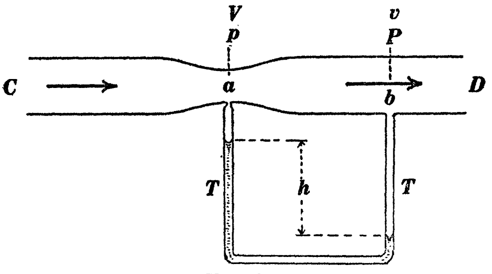


FIG. 3.

Air flows through a tube *CD*. Where the section of the tube is small, at *a*, the velocity of the air is large; and where the section of the tube is large, at *b*, the velocity of the air is small, as indicated by the two letters *V* and *v*. Furthermore where the velocity is large the pressure is small and where the velocity is small the pressure is large, as indicated by the two letters *p* and *P*. The low pressure of the air at *a* draws the liquid up in the tube *T*, and the large pressure of the air at *b* pushes the liquid down in Tube T'.

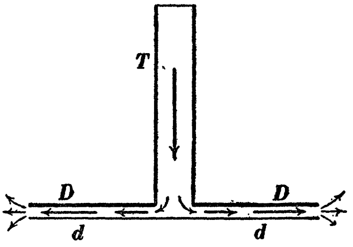


FIG. 4.

A brass tube *T* is soldered to a brass disk *DD*, and air is blown through the tube *T* and against the loose disk *dd*. The air between the two disks has a large velocity, but this velocity decreases greatly towards the edges of the disks because of the great increase of the sectional area of the air stream, and it decreases still more as the air (by virtue of its momentum) pushes itself out between the edges of the disks into the surrounding air. Now the pressure of the surrounding air (where the velocity is low) is high, and the pressure of the air between the disks (where the velocity is high) is low. Therefore the surrounding air exerts greater force in pushing the disks together than the force exerted by the air stream in pushing the disks apart. That is, the disk *dd* sticks tighter and tighter to *DD* the harder one blows through *T*.

This represents a hydraulic analogue of Fig. 4. The rapidly moving water on the disk is at a low level, and it lifts itself to the higher level of the still water in the basin as it flows off the edge of the disk *dd*. Therefore the still water underneath the disk has a higher pressure than the moving water on top of the disk so that the disk is held up. The pin *p* serves to prevent the disk from moving sidewise.

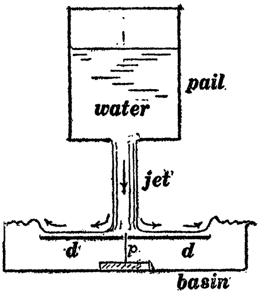
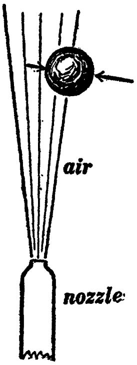


FIG. 5.



This shows a light ball floating in an air jet. The air in the jet pushes up on the ball and keeps it from falling, and when the ball starts to fall out of the jet the surrounding air pushes it back into the jet because the pressure of the surrounding air is high (where the velocity of the air is low) and the pressure of the air in the jet is low (where the velocity is high).

FIG. 6.

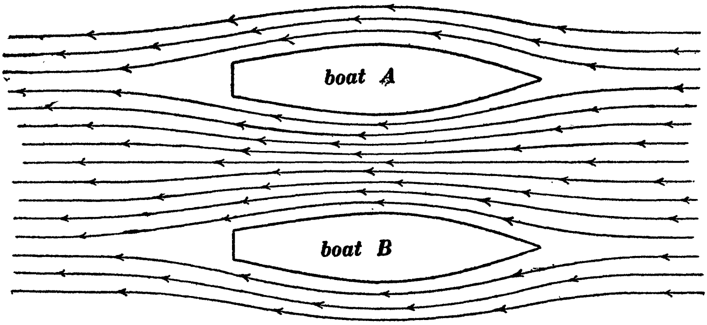


FIG. 7.

This represents two boats moving along side by side in still water, or what amounts to the same thing, two boats standing side by side with water flowing past them. The stream is greatly compressed in the region between the boats, and the velocity in that region is high, higher indeed than it is on the outside of either boat. Therefore the water level (which corresponds to pressure) is lower between the boats than it is on the outside of either boat, and the higher water on the outside of the boats pushes the boats together. It is a well known fact among navy men that two boats which are steaming along side by side are powerfully drawn towards each other.

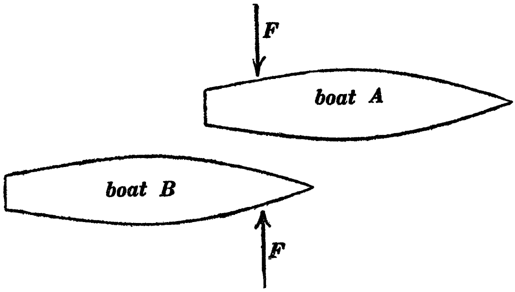


FIG. 8.

The most serious condition which can arise when one boat is steaming past another is shown in this figure. The two forces *FF* with which the boats are pushed towards each other tend to turn the boats, thus the boat *B* is powerfully turned towards boat *A*, and a collision is almost sure to take place before the rudder can be properly set to keep the boat from turning.

The effect which is described in connection with Figs. 7 and 8 may be shown by blowing between two light rubber balls which are suspended as here shown. When one blows between the balls the balls come together with a bump.

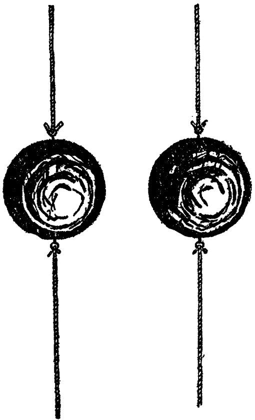


FIG. 9.

The following four figures lead up to an understanding of the curved flight of a spinning baseball, and Figs. 10, 11 and 12 must be thought of together.

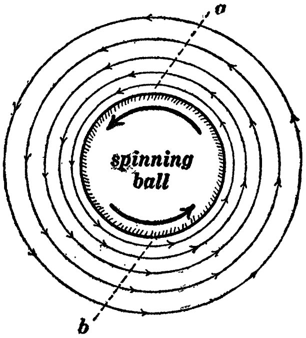


FIG. 10.

This figure shows the whirling motion of the air in the neighborhood of a spinning ball.

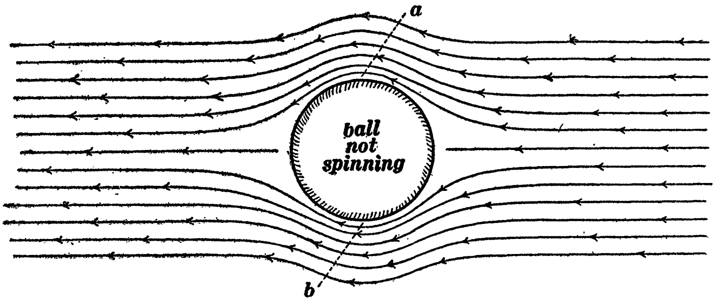


FIG. 11.

This figure shows the motion of an air stream flowing past a ball which is not spinning. The stream splits and flows equally around the two sides of the ball.

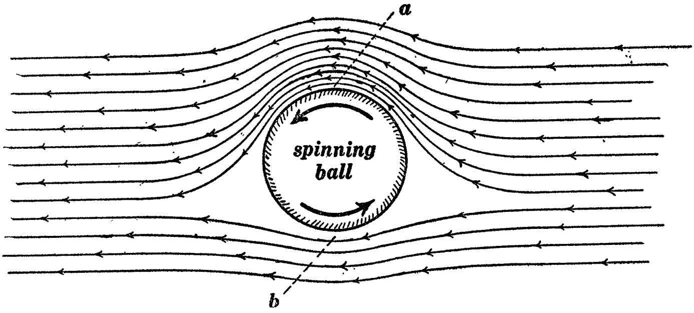


FIG. 12.

This figure shows the motion of an air stream as it flows past a spinning ball. The velocity of the air at the point *a* is partly due to the spinning motion of the ball as shown in Fig. 10, and partly due to the stream as shown in Fig. 11. That is, the two causes which are shown in Figs. 10 and 11 act together to produce a large velocity at *a*, and the two causes which are shown in Figs. 10 and 11 oppose each other and produce a small velocity at *b*. Therefore the velocity is large at *a* and small at *b*, and consequently the pressure is large at *b* and small at *a*. The air at *a* therefore pushes down on the ball with a small force *f*, and the air at *b* pushes up on the ball with a large force *F* as shown in Fig. 13.

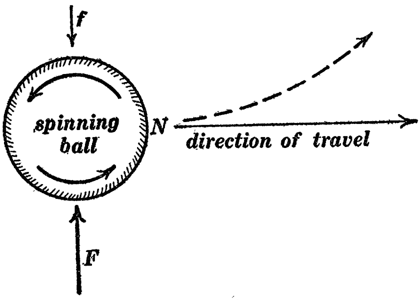


FIG. 13.

The action in Fig. 12, where a stream of air flows past a spinning ball, is exactly the same as the action which takes place when a spinning ball travels forwards through still air, as shown in this figure. A large force *F* pushes up on the spinning ball, and a small force *f* pushes down on the spinning ball. Therefore the ball curves upwards as shown by the dotted arrow. Of course the upward force *F* must be much greater than the downward force *f* to produce an upward curvature, because the downward pull of gravity on the ball must be overcome.

The point *N* on the ball may be called the *nose of the ball*. This nose is traveling sidewise because of the spin of the ball; and the ball curves towards the side towards which the nose of the ball is traveling.

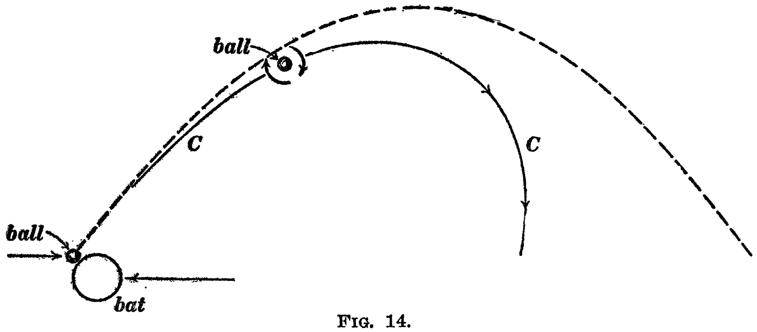


FIG. 14.

The curve *CC* shows the path of a high foul. The ball strikes the bat and is set spinning in the direction shown by the small curved arrows. If the ball were not spinning it would follow the dotted line, but the spinning of the ball causes it to be deflected continually to one side, as explained in connection with Fig. 13, so that the ball actually follows the path *CC*.

A ping pong ball is thrown upwards by shooting it with the thumb, marble-fashion, so that the ball is set spinning in the direction of the curved arrows. The dotted line shows the path which would be followed by the ball if it were not spinning, and the full line shows the actual path of the ball.

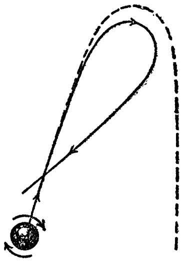


FIG. 15.

THE SPIT BALL

Imagine a perfectly smooth ball traveling through still air. There is certainly no reason why the ball should be pushed to one side rather than the other; therefore one may conclude that the ball will not be pushed to either side! In the same way there is no reason why a sharp-pointed stick standing exactly vertical on a hard floor in a quiet room should fall one way rather than another; therefore we may conclude that the stick will not fall either way! This is good logic in both cases, but it is bad physics. The ball *is* pushed to one side or the other, and the stick always *does* fall. The vertical stick is in what is called an unstable state, and an infinitesimal disturbance is enough to start the fall in some direction, and then away she goes! Also the motion of a smooth ball through still air involves a condition of instability, and an infinitesimal disturbance is enough to start an action which rapidly develops and pushes the ball decidedly to one side or the other.

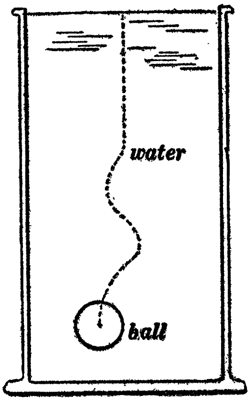


FIG. 16.

This shows the irregular zig-zag path of a smooth ball (not spinning) as it sinks in water. The ball travels nearly straight until it attains a certain velocity, and then it follows a zig-zag path until it reaches the bottom of the vessel. A smooth ball (not spinning) also describes an irregular zig-zag path as it travels through the air, but the irregularities are much less than in the case of a ball moving through water because the density of the air is so small as compared with the density of water. The cause of this irregular zig-zag motion is analyzed in the following figures.

Every one is familiar with the peculiar curling motion of a rising streak of cigar smoke in still air. The first part of the stream is smooth, but as the velocity of the rising smoke increases, the stream becomes unstable and develops into a complicated set of eddies and whirls. The boundary between a rapidly moving stream of air or liquid and a stationary body of air or liquid is unstable, especially if the velocity of the stream is great; and this instability always shows itself by the development of a complicated set of eddies and whirls.

FIG. 17.

When a gas jet is not turned up too high, the velocity of the gas in the jet is low and the stream of gas is smooth as shown by the sketch *a*. If the jet is turned up too high, however, it becomes very turbulent (full of eddies and whirls) as shown by sketch *b*, and in this case the flame produces a roaring sound. The loud hissing sound of a steam jet is due to the extremely fine-grained eddies and whirls which are formed along the boundary between the rapidly moving steam and the adjoining still air.

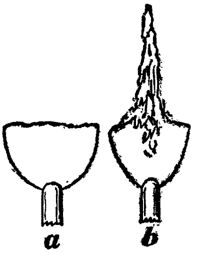


FIG. 18.

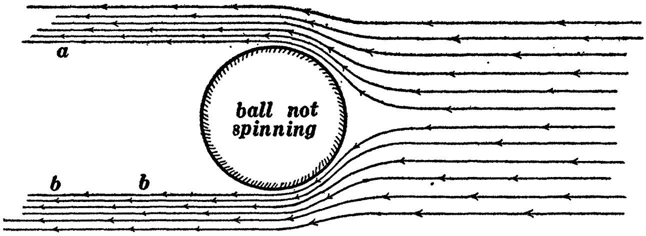


FIG. 19.

This figure shows a stream of air moving past a ball which is not spinning, the velocity of the stream being rapid so that the stream breaks away from the ball as shown, giving two boundaries *aa* and *bb* between rapidly moving air and stationary air. Such boundaries are unstable as exemplified by the behavior of the smoke jet in Fig. 17 and the gas jet in Fig. 18. Therefore eddies and whirls develop along *aa* and *bb*, and as a result the stream at *aa* will be at one instant deflected downwards (in the figure) and at another instant upwards. The same thing may be said of the boundary *bb*. Whenever the stream at *aa* (or *bb*) is deflected downwards (in the figure) a force of reaction is brought to bear upon the ball pushing it upwards (in the figure), and whenever the stream at *aa* (or *bb*) is deflected upwards a reacting force is exerted on the ball, pushing it downwards. Therefore the ball is pushed irregularly to one side and the other repeatedly. The action here described refers to a stationary ball with air flowing past it, and exactly the same effects are produced when a ball moves swiftly through stationary air or water, and the irregular side forces which are exerted on the ball cause it to describe a zig-zag path.